VIRTUAL REALITY AS A TOOL TO ASSESS PERCEPTION OF SAFETY AND COMFORT FOR CYCLISTS IN SINGAPORE

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Abstract

This research seeks to understand how existing roads can be redesigned to address cyclists' concerns of safety and continuous movement in Singapore. In particular, previous and ongoing initiatives to improve the cycling infrastructure in Singapore clearly struggle with the question of whether and when cyclists should belong to the pedestrian or vehicular realm. Based on experiences in other cities, it is clear that the propensity to cycle is directly related to how well the infrastructure caters to cyclists' need for safe, direct and comfortable routes.

When designing such infrastructure, planners face recurring dilemmas and trade-offs. A cycling route along a major road might improve directness, but designing it to be safe and to support continuous movement can be very challenging as potential conflicts with public transport, cars and pedestrians must be considered. To meaningfully compare alternative treet designs, we must understand how people perceive and react to different design options. To this end, we introduce Virtual Reality (VR) application as a research tool to test perceptions and behaviour.

The VR models are based on 3D model animated with traffic microsimulations from Vissim, integrated in Unity. The result is a set of possible future street designs that resemble reality and are adapted to specific Singaporean circumstances. Having applied this methodology for streets in Singapore and tested with more than 200 hundred participants , we find that visual and temporal feedback enabled by VR makes several important design parameters observable and allows researchers to conduct behavioural surveys to understand how people will respond to different design options. In addition, we conclude that such VR applications open new avenues for citizen engagement and communication of urban plans to stakeholders.

Introduction

Despite having a dense and polycentric urban structure, the modal share of bicycles in Singapore is only about 1%, which is very low compared to other cities in Asia and around the world ("Cycling Mode Share Data for 700 Cities" 2014). According to prior research, several factors are identified as barriers to widespread adoption of cycling as a means of commute in Singapore. Prominent among them are topography, weather, and trip distance. But the barriers that appears most consistently between studies is the perceived hazard associated with cycling near motorists (Sanders 2013) and the lack of appropriate dedicated infrastructure for cyclists.

Urban development patterns and morphology can hinder or facilitate active mobility. Indeed, a growing body of research provides evidence of a link between the built environment and active living (Ewing, Schieber, and Zegeer 2003). Empirical evidence has shown that mixed use compact cities are more attractive for pedestrians and cyclists while low density mono-functional sprawls deter active mobility (Saelens, Sallis, and Frank 003). It follows that in order to reduce our dependence on automobiles and move towards a car-lite future, dense mixed use urban development designed for human scale and walking speed is essential.

Additionally, street design plays a significant role in determining how pleasant, safe and comfortable the walking and cycling experience is (Buehler and Dill 2016). It can potentially encourage modal shift to active forms of transport. However, the prevailing rhetoric in Singapore creates an impression that cycling can be an unpleasant and unsafe

experience (Tan 2016). The fact that many cyclists prefer to cycle on the sidewalks in Singapore, which has been legalised recently, support this argument.

In our study we would like to focus our concerns on the latter. To what extent can streets that are designed for active mobility influence perception of safety and comfort for cyclists in Singapore? What would be the attributes of such a design?

Methodology / Why Virtual Reality

The goal of our study is to understand how and what type of street designs can influence perception of safety and comfort for cyclists in Singapore through interviews and surveys. Since we are focussing on the question of 'perception' of safety, and not actual traffic safety risks associated with design typologies, we need to be able to effectively communicate design options to gauge perception accurately. This means, how the design options are visualized and communicated play a significant role in determining to what extent we can understand perception of safety of cyclists.

Visualizations have always played an important role in communicating plans and policies that support active transport modes. Since adding bicycle infrastructure often means a large public investment or a trade-off for space with other transport modes, visualizations are often used in early stages to illustrate the gains of a project with regards to traffic safety, liveability or social inclusion. They are also used in research applications to study the impact of such infrastructure on people's behaviour. It allows researchers to quantify user reactions towards infrastructure that does not exist today and guide planners through dilemmas when designing future infrastructure.

So far, visualizations to communicate future street designs rely heavily on pictures, photomontages, maps or simulation videos. Researchers have used sketches or photomontages in stated preference surveys to communicate design, for example to understand how safe from crime people feel given different street design and levels of street lighting (Börjesson 2012), how urban design variables impact pedestrian route choice (Erath 2015) and measure qualitative attributes of public spaces (Hurtubia, Guevara, and Donoso 2015). Researchers also use simple 3D visualisations, (Martínez and Barros 2014) to investigate what pedestrian infrastructure design variables, such as presence of barriers and trees, do people value. A key advantage of using computer-generated visualisations as compared to sketches is that it allows to easily collate design scenarios by selectively activating the relevant digital layers.

Another study employed a stated preference survey using photo montages to quantify user preferences for cycling infrastructure in an urban context (Rosetti et al. 2016). Photo montages have an edge over just using photos of different design configurations, since such montages illustrate the street segment under different street design scenarios and therefore allow to control for confounding effects such as unintended variations with regards to vegetation, urban design or weather conditions. However, the parameters that can be altered are restricted and sometimes difficult to depict realistically. Also the impact of different speeds, changing eye level perspective, crowding, sense of space and enclosure are harder to perceive in such montages. All these methods are riddled with limitations. Prominent among these are:

1. Often traditional 3D models and design drawings like plans and sections fail to communicate the eye level perspective of cyclists. This can lead to gross oversights 6 like blind spots at turns.

2. Sense of space and enclosure is not palpable in images and videos.

3. Sightlines and visibility are also important factors that may be neglected in a still image. The spectator needs to understand what is visible to them as they move from point A to B on a street. Not only is it important for the spectator to know what is visible to them, but also how visible they are themselves. It is therefore crucial to populate the visualizations with multiple agents.

4. An important factor that determines the quality of a street and perception of safety is the speed and volume of traffic. These are hard to communicate in still images, but can be addressed by simulations and videos.

5. Edge conditions and adjacencies are an important attribute of streets that may not be obviously represented in traditional visualization. While the cyclists in moving on the street, she is also moving along a certain edge condition, which plays a role in the overall experience.

6. The idea of time needs to be communicated clearly when assessing perception on a street. As a spectator moves slower, she observes more. Perception of risk from surrounding traffic is influenced by proximity and speed of surrounding traffic, as well as the spectator's own speed.

7. Audio feedback is a key parameter that cannot be captured through imagery, but plays a significant role in determining how pleasant the cycling experience is on the street. Ambient sound of motorized traffic can be very invasive and proximity to the traffic lane, speed and volume and type of traffic heavily influence this. Additionally, 6sound is also useful as a warning signal for the cyclist.

8. Weather is a big determining factor in whether people choose to cycle in Singapore. Visually it is hard to capture the exacerbating effect of direct sunlight, and even harder to discern the mitigating effect of shade from a tree versus a mechanical device.

Traditional methods of visualizations partially address these limitations, but there is no clear holistic solution. However, recent advances in computer graphics and lowered barriers to entry into the field of video games has opened new opportunities for generating realistic 3D scenarios that are suitable for behavioural studies (Mostofi Darbani et al. 2014). Researchers have applied video game environments to study pedestrian route choice and reaction to information in evacuation scenarios. (Doirado et al. 2012; Ribeiro et al. 2013) Technological development in the field of Virtual Reality (VR) opens new windows for practical applications and scientific insights. VR allows the user to immerse in the future environment, which expands opportunities for stakeholder involvement and in- depth evaluation of user perception.

VR is used frequently in the gaming industry, but urban and transport planning is yet to catch on to this method of visualization, and currently relies heavily on pictures, photomontages, maps or simulation videos. VR allows the user to immerse in the future environment, which opens new doors for in-depth evaluation of user perception. By employing VR applications in surveys we attempt to distil behavioural evidence that can guide planners through dilemmas when designing future cycling infrastructure. At the same time, we are studying efficacy of VR as a method for assessing perceptual behaviour as opposed to traditional methods of visualization.

In order to understand if VR can address some of these limitations and give us a better understanding of cyclists' perception of safety, we set up a two-part experiment 'Bike to the Future'. Through this experiment we aim to answer the following questions

A. Is virtual reality an effective tool to communicate street design options to people, as opposed to traditional methods of visualisation?

B. What are the barriers to modal shift to cycling in Singapore? What role can street design play in influencing people' s choice to cycle or not?

The Experiment

Given the low popularity of cycling in Singapore, we set up a VR experiment in order to understand what would make

Figure 1: Redesigned Seng Poh Road, modelled on 3DS Max and rendered on Unity
Source: URA and Michael Joos,2016.

Singapore more walkable and cycleable. The purpose of the experiment was to redesign certain streets in Singapore to incorporate cycling infrastructure and create a 3D virtual environment of the new design. Participants were asked to cycle on the redesigned streets, in a public exhibition set up, and give feedback through a survey questionnaire. There are two parts to setting up the experiment – first, to design the 3D model and create a virtual environment and second, to design the survey and feedback system. For the first part we created a software pipeline between three main platforms.

3D model

We use several types of 3D modelling software to create our models. In the case of this experiment we worked with 3Ds Max in combination with Sketchup. We procured a high definition 3D model of the site from Urban Redevelopment Authority (URA) in Singapore. This site in Tiong Bahru neighbourhood was selected for several reasons. First, URA was able to provide high definition 3D models of latest existing conditions in only some pre-selected areas, which included Tiong Bahru. Second, the Tiong Bahru neighbourhood provided the opportunity to attract a diverse audience given its popularity among a wide group of people. Third, the neighbourhood offered the potential to introduce a new street design with minimum spill-over effects on the surrounding road network.

To begin with, we studied the broader network plan in the neighbourhood and modified it to create pedestrian and bicycle friendly streets and zones, based on current land use, traffic pattern, wider street network configuration and observed footfall. Consequently, new street designs were introduced as infill in the existing neighbourhood, to accommodate different type of cycle lanes and increased pedestrian accessibility.

A cycling loop around Tiong Bahru market was finally chosen

as a pre-determined path for participants to cycle on in the experiment. This selection was made in order to showcase three types of bicycle infrastructure, distinct from each other – first was a one-way traffic street which was modified to add cyclist priority stamps on the road, with no dedicated lane or markings, in the direction of car traffic. The second was a pedestrian only path that was modified to have painted and separated cycle lanes. The third was a two way traffic street with on street parking that was transformed into a pedestrian plaza with shared cycle lane with minimal markings. The rest of the infrastructure, including surrounding buildings, most trees and streetlights, remained unchaged. This model was exported as a .3DS file to the game engine.

Traffic micro-simulation

A key element of the VR experience is the movement and interaction of surrounding agents – cars, buses, cyclists and pedestrians. Therefore, a traffic micro-simulation was generated for the new design.

Based on expert knowledge and the experience of other researchers, the implemention of Artificial Intelligence in a game engineto simulate realistic traffic scenarios is not a straighforward task (Prendinger et al. 2014). Therefore we decided to integrate microscopic traffic simultion software with a game engine to generate VE. Current traffic microsimulation software packages such as PTV Vissim, Caliper Transmodeller, Sumo or TSS Aimsun offer possibilities to model complex but realistic multi-modal traffic situations. For this research project, the traffic microsimulation tool PTV Vissim has been chosen. Vissim offers the widest range of urban traffic simulation capabilities including public transport, individual cars, trucks, bicycles and pedestrians (Twaddle, Schendzielorz, and Fakler 2014). Vissim is to our knowledge also the only traffic simulation software that provides interfaces to interactively interact with the simulation, a crucial feature for immersive VR applications.

Integration of outputs in Game Engine

Both the 3D model and traffic microsimulation need to be combined , interact with the environment and be presented on a VR head-mounted-display (HMD). Of the many game engines available to do this, we chose Unity because of its visual capabilities, VR support, ample range of file formats and ease of use. Some of the more noticeable visual improvements when going from Vissim to Unity are:

- Physically based lighting and shadowing
- Global illumination
- Reflections
- More realistic skies
- Better texture filtering and antialiasing
- Post-process effects (Depth of field, motion blur, bloom, etc.)
- Modelling of audio

The logic behind the existing pipeline is to simulate the desired scenario in Vissim and to export the traffic related data to Unity aiming at achieving a better quality of the 3D model animations. The main aims for the integration pipeline were - rendering realistic visualization of future traffic as stills, short video, 360-degree videos and Unity executables that allow users to interactively explore the simulated scenarios in 3D.

Bridging Vissim with Unity wasn't straightforward: Unity doesn't have built-in support for Vissim file formats yet. However, it was possible to write Unity scripts for this purpose (Joos 2016). The export/import mainly consists of trajectories of the simulated interactions between pedestrians, bicycles and cars and the commands related to the traffic lights. The export from Vissim is a .csv file that writes simulation second, pedestrian/vehicle identifier, type of pedestrian/vehicle, x-, y- and z-coordinates. For the vehicle, two coordinates (front and rear) are required in order to extract the size and orientation of the object. Since Vissim runs its simulation at a fixed frequency (a configurable integer between 1 and 10 steps per second), and game engines tend to run at a much higher and variable rate (VR requires at least 90 frames per second for a comfortable experience), a custom script was developed to interpolate pedestrian/vehicle movement between simulation steps. The traffic light program is written in a simple, exportable XML-file.

Other scripts were also written to improve the visual quality of the traffic simulation data: to individually rotate each vehicle's wheels in accordance to their speed and radii; randomize vehicle models across traffic data to achieve more natural results; full body animations and animation transitions for pedestrians depending on their movement speed and light animation for traffic lights.

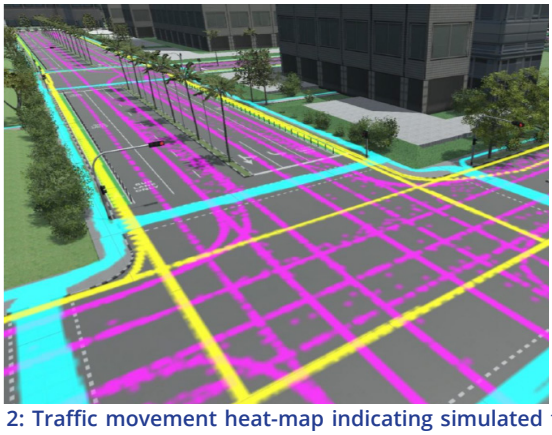

Figure 2: Traffic movement heat-map indicating simulated traces of pedestrians (cyan), cyclists (yellow) and vehicles (magenta) projected on 3d model.

Some of the scripts weren't dedicated to the final visual appearance, but still they played a crucial role in development. These scripts, for example, helped us to identify issues outside of Unity by visualizing the input data. E.g. a script to generate a traffic movement heat-map, to observe which areas are more/less frequented by simulation agents (Figure 2), or to identify if an agent takes an undesired path which helps to verify the simulation setup.

Experiment

Figure 3: Cycling Experiment on Park(ing) Day in Tiong Bahru
Source: Lina Meisen

The physical set up of the experiment involved two bicycle trainers, two head mounted gears (HTC Vive and Oculus Rift), two PC's and two display monitors to view the videos as the participants cycled through. The VE experience was set up as a 360 degree video with no steering, braking or pedalling control. Participants were asked to hop on the bicycle trainer and cycle virtually along the cycling loop consisting of three street segments with different types of cycling infrastructure.. There were three types of transformations - a street which was pedestrian only in both before and after scenario, except that the after scenario incorporated better lane markings for cyclists. The second was a one-way road, that had minimum transformation – only the addition of cyclist priority road stamps and signs, but no dedicated cycle lane. The third witnessed complete transformation, from a traffic road with on street parking to a pedestrian plaza with shared bike lanes.

In conjunction with the immersive cycling loop, the participants were also asked to fill a short questionnaire.

The survey was designed to test perception and retention value of VR, and the different attributes noticed in VR. It consisted of three parts. First, pre-experiment survey determined the participant's current travel behaviour and attitudes towards active mobility. Participants were asked if they would cycle on the three streets, as they are now, (as shown in images), themselves and with a ten year old child. Second, the participant were asked to cycle virtually along the cycling loop consisting of the same three street segments redesigned with different types of cycling infrastructure. During the VR ride, participants were asked to think aloud and describe their experience. In the third part following the VR experiment, participants were asked that given the improved infrastructure design, how would their mobility behaviour and attitude be influenced. This is a step towards understanding if VR is a compelling means of communication, that impacts public perception. Participants were also asked what they 'liked' and 'disliked' about the new design, to deduce what they retain from the experience. This preliminary test will help us prepare better for larger controlled studies at a later stage. Finally, respondents were asked how the usage of VR added to their experience as compared to conventional photo montages.

The experiment spanned over two days in semi-open public spaces in Singapore. First, we placed our experiment setup at the occasion of Park(ing) Day on the very parking lot where the ride around the cycling loop starts in the Virtual Reality scenario. (Figure 3). A random sample approach was applied when motivating pedestrians in the area to participate in the experiment. However, it turned out to be rather difficult to motivate the elderly to participate. In addition, potential participants were informed about the nature of the experiment when approached. Therefore, the sample is subject to a certain degree of self-selection bias. Colleagues working in the same research institutions as the researchers were also invited to participate in the experiment.

We conducted the survey again in an architecture/urban design –themed exhibition pavilion with considerable pedestrian footfall in Singapore's city centre at Raffles Place. While exactly the same VR scenarios were used again, the phrasing of some questions like, how VR added to the experience as compared to conventional renderings, was simplified based on the feedback collected in the first experiment. The recruitment again followed a random sampling approach. Participants mainly belonged to design and planning disciplines due to

the nature of the setting. Yet again, younger people, between the age 20 and 40, were more enthusiastic participants and formed a bulk of the respondents. A panel discussion about 'how to re-design Singapore streets for active mobility', was organized in conjunction with the experiment. This meant, a fair number of participants were already active cyclists or champions of active mobility, which might add a bias. In total 223 questionnaire responses were collected.

Results and Observations

Three types of results were collected during the experiment. First, from survey forms filled out by participants. Second, were narrated experiences by participants during the VR 'ride', through a think aloud protocol. Third, was anecdotal evidence gathered from informal discussions with participants, comments and suggestions in the survey responses, media response and a panel discussion.

Responses to the first part of the survey confirmed our initial hypothesis that the primary reason why people choose to not cycle in Singapore is safety concerns. Bad behaviour of motorists towards cyclists and lack of appropriate infrastructure were among the top deterrents for cycling. Additionally, unsuitable weather was also seen as a major hindrance. This parameter is difficult to test in VR due to technological limitations.

The second part of the questionnaire asked whether more people would consider cycling on a street if it was designed for cyclists. Across the board, the number of participants who preferred to cycle in the 'after' scenario was higher. This led us to believe that irrespective of the magnitude of change between before and after, provision of any infrastructure for cyclists, minimal to exclusive, had positive impact on the mode choice of respondents.

Finally, when asked to compare their understanding of the street design between photographs and VR, participants felt that the movement of cars, pedestrians and cyclists around them had the most added value to their understanding of the design. They felt that VR added a 'vibrancy' to the street that was missing in photographs. This can be interpreted as a combination of the movement of the agents around the participant, the participant themselves and the ability to view a much larger canvas than a photograph, that adds a sense of vitality that might not come through in a photograph.

When asked what was missing from their experience, most participants alluded to the lack of control (steering and braking) and sound. Some also raised concerns about validity of the results, since external weather factors were not being considered in people's choices. While this is a valid concern, for the purpose of this research we nonethlessfind the feedback valuable, as it addresses several other limitations of traditional methods of visualization, but also highlights the limits of VR.

Many of the participants had little to no prior experience of cycling in Singapore. For a 5majority, the stated reason was weather, safety concerns and lack of cycling infrastructure. These participants reacted positively to virtual cycle ride, expressing surprise at how safe and pleasant the ride felt. This pointed to the effectiveness of VR as a potential tool for awareness building and public engagement.

Conclusion

VR as technology clearly has a long way to go, if our goal is replicate reality with maximum fidelity. However, for specific purposes, it can be used as a valuable extension to the current toolset available to architects, planners and researchers to communicate street design options.

Reviewing how visualizations have been used in research and practice, we identified how VR applications can fill existing methodological gaps when it comes to studying perception to support active mobility and future mobility solutions that do not exist today. VR has potential to help understandhow the design of the built environment influences the perception of safety and comfort for walking and cycling more directly and concisely than conventional methodologies such as longitudinal or cross-sectional approaches. VR can also be helpful to explore human interaction with future forms of mobility such as autonomous vehicles that currently can't be studied in real environments. We also expect that the features of consumer-grade VR hardware such as display resolution and availability of suitable human machine interface devices will continue to improve offering even more opportunities for application in transportation research and planning.

In any field of application, it will be important to clearly demonstrate how VR applications can fill existing methodological gaps or lead to more effective and efficient study designs. A key research question to be answered will be whether results from studies that employ VR applications will lead to similar results as conventional, proven methods (Kuliga et al. 2015). This can for example be addressed by comparing the results of stated preference surveys that employ VR-based visualization with such that used conventional illustrations, photomontages or videos of existing environments.

There are obviously many more applications to be explored beyond what we were able to cover with the presented experiment. For example, a direct integration of Vissim and Unity through a real-time interface can provide the fundament for implementing a VR driving simulator. There are already various groups that showcased how a

conventional bicycle trainer can be converted to a human machine interaction interface of a VR cycling simulator (de Leeuw and de Kruijf 2015; Bottone, Smith, and Thacker 2015; Widerun Inc. 2015) that allows participants to explore various street design in a controlled setting. While the first tests with such VR cycling simulators show promising results, also a few challenges for conducting behavioural studies have become clear: participants require a certain time period to familiarize with the new technology and the combination of immersive visualization but lack of actual feedback of physical forces, e.g. when bending around a corner can cause immediate feelings of motion sickness. Multi-user settings also offer interesting field of applications that for example researchers interested in studyingthe behaviour in evacuation scenarios have tested recently (Moussaïd et al. in press; Doirado et al. 2012).

As immersive virtual environments become a more accessible technology, the potential applications are fast expanding beyond traditional gaming industries. Transport planning and street design is one such application.

In order to promote active mobility and increase the modal share of cycling, it is important for designers to understand the perception of the end user, many of whom have little to no cycling experience, as well as the future users to understand clearly the added value and experience of the future street design options. For both purposes, VR can be an effective tool of choice.

While real experiences can never be entirely replicated, VR should be considered an additional communication tool, with evident added value, and particular limitations. These limitations are yet to be clearly understood, defined and quantified. The case studies presented in this paper, help to further clarify the applications and limitations in this regard.

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